USAARL Report No. 2016-17

Facilitating the Transition from Bright to Dim Environments

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United States Army Aeromedical Research Laboratory

Visual Protection and Performance Division

March 2016

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
4-3-2016	Final	

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Facilitating the Transition from Bright to Dim Environments	
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Walsh, David; Lattimore, Morris R.; Still, David L.; Temme, Leonard A.; Weiser, Will; Cox, Heath; Allen, Roddricus; Statz, Jonathan K.; Riggs, Daniel	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
U.S. Army Aeromedical Research Laboratory P.O. Box 620577 Fort Rucker, AL 36362	USAARL 2016-17
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
U.S. Army Medical Research and Materiel Command 504 Scott Street Fort Detrick, MD 21702	USAMRMC
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

High on the list of desired capabilities for Warfighters, enumerated by MG Walter Wojdakowski at the 2008 Fort Benning "Lab Day," was the development of combat protective eyewear with lenses that would instantly change the amount of light transmitted based on incident lighting conditions. This study compared five different eyewear conditions: (1) no eyewear, (2) Approved Protective Eyewear List (APEL) clear eyewear, (3) APEL sun eyewear, (4) step-filter eyewear, and (5) electro-optical eyewear. Dark adaptation responsiveness and target recognition were most effective with the step-filter eyewear compared to the control, clear, and sunglass conditions. The step-filter and electro-optical eyewear were both subjectively preferred over all other approaches. Operational performance results while wearing either of these two optical devices were equally effective and consequently the ultimate fielding decision could be based on acquisition-related differences (cost and/or time).

15. SUBJECT TERMS

Military Combat Eye Protection, Dark Adaptation, APEL

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Loraine St. Onge, PhD
UNCLAS	UNCLAS	UNCLAS	SAR	21	19b. TELEPHONE NUMBER *(Include area code)* 334-255-6906

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Acknowledgments

This research was supported in part by an appointment to the Postgraduate Research Participation Program at the U.S. Army Aeromedical Research Laboratory administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the U.S. Army Medical Research and Materiel Command.

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Background

Warfighters are required to wear Military Combat Eye Protection (MCEP) in a deployed setting at all times to protect their eyes from ballistic hazards such as shrapnel, as well as to provide protection against blast effects to the eyes (Thomas et al., 2009). Warfighters are issued an MCEP kit (that has been identified and itemized on the Authorized Protective Eyewear List [APEL]), which includes a frame, with reduced transmittance, i.e., sunglass, lenses, along with clear lenses. The clear and sunglass lenses can be interchanged without tools in about a minute or two. However, the primary operational task that remains problematic with MCEP use is the occasion when the Warfighter is required to transition from a brightly lit outdoor environment to a dark interior space (e.g., in buildings, caves, and other possible hiding places). Presently, Warfighters have four options, none of which is satisfactory, because they all put Warfighters at risk to one degree or another. First, Warfighters can remove their MCEP sunglasses, leaving their eyes unprotected from ballistic injury. Second, they can switch from MCEP sunglasses to clear lenses; however, this requires that operators pause, take their hands off their weapon, remove the sunglass lenses, and install the clear lenses, which is operationally very problematic. Third, they can simply leave the MCEP sunglasses on, which would make the dark interior even darker, limiting visual capability even more, thus giving the enemy an even greater tactical advantage. Finally, the Warfighter can use only clear lenses in the MCEP. This last approach also reduces visual capability in the dark interior spaces. In this case, the reduction in visual performance is due to the bright exterior illumination's detrimental effects, serving to delay dark adaptation.

The basic problem in dark adaptation is that prior exposure to bright sunlight within the previous 15 to 20 minutes makes it harder to immediately see clearly in the dark (Barlow, 1972). As an example, consider an individual going into a movie theater on a bright Saturday afternoon to catch a matinee. Initially, upon stepping into the dark theater, the individual experiences the subjective sensation of being functionally blind. After standing at the back of the theater for a few minutes, the visual system recovers enough to permit easily finding an empty seat. In this situation, invariably the individual does not so much see the empty seat, but an empty space, missing a silhouette of the audience against the lighted movie screen. Moving down the aisle to the seat, the individual trusts that there are no trip-hazards in the aisle, since the floor is poorly defined despite the dim aisle lighting. The point is that it takes time for the human eye to develop enough visual sensitivity to see effectively in a dark environment following exposure to a brightly lit environment. The examination of this and related phenomena have been one of the major topics of scientific investigation for vision and its related sciences, not only because it is such a profound effect, but because it has so many practical military implications, limiting visual performance in vitally important operational situations.

During the 2008 Infantry Lab Day at Fort Benning, Georgia, MG Walter Wojdakowski briefed the current gaps in technology needed to be addressed to improve Soldier survivability in the contemporary combat environment. High among the list of desired capabilities for Warfighters was combat protective eyewear with lenses that would instantly change the amount of light transmitted (instantaneously-varied optical density) based on changing or altered lighting conditions. It was noted that although currently authorized MCEP have interchangeable clear and tinted (sunglass) lenses, Soldiers may have to remove their MCEP in order to manually exchange

the lenses. Worse than that, they may even have to remove their helmet to get access to the MCEP, in order to then swap out the lenses. This makes them vulnerable to combat-induced, life threatening injuries. At best, the entire process is a time-consuming event that might be difficult or even impossible to accomplish at all, depending on the operational situation. Given these choices, many Soldiers opt not to wear their combat eye protection in order to preserve their visual sensitivity under variously encountered lighting conditions. The research challenge is to find a better option for the Warfighters to overcome this challenge.

There were two purposes to the present study. First, to identify, evaluate, quantify, and refine methods/procedures that enhance the ability of our military personnel to efficiently and rapidly transition from light to dark environments, then to function effectively. Second, to determine how best to facilitate Soldier transition from bright to dim environments using currently available lens technology, which addresses one of the operational gaps frequently identified by Infantry Warfighters having served in Iraq and Afghanistan.

Methods

Subjects

Twenty-four active duty Soldiers ranging from ages 19 to 40 (mean = 27 ± 4.4) were recruited for the study. This age range reflected the operational population in which we were most interested, since the rates of dark adaptation of those above 40 may be affected by age (e.g., Robertson and Yudkin, 1944; Birren and Shock., 1950; Jackson et al, 1998; Jackson and Owsley, 2000). Volunteers were required to have best-corrected visual acuity of at least 20/25 in the eye used for sighting a rifle. The study protocol was approved by the U.S. Army Medical Research and Materiel Command (USAMRMC) Institutional Review Board. Each subject provided written informed consent before participating.

Equipment

Four filter approaches/technologies for accelerating the effective transition from a light to a dark environment were used in the study. A control condition (CC), in which no corrective lens or filter was used, served as the basic performance level against which all other filter conditions were assessed. Four filter approaches tested were as follows:

1. Clear protective lenses (CL), in which one of the MCEP included in the APEL were worn with its clear lenses in place (figure 1A).

2. Standard sunglass protective lenses (SL), with a constant optical density, in which the same MCEP selected for CL were worn with the SL (figure 1B).

3. A step-filter or bi-gradient lens (SF), in which the lens optical density that will be worn is not constant (as in the SL condition) but an abrupt step function such that the top half of the sunglass or filter has an optical density as close as possible to 1.0, while the bottom half of the sunglass or

filter has an optical density of 0.0. The SF condition also used an MCEP, but was fitted with custom-made step-filter bi-gradient lenses (figure 1C).

4. A newly available electro-optical lens (EO) (figure 1D).

Figure 1. Eyewear worn in study. From top to bottom: A) clear lens MCEP; B) sunglass MCEP; C) step-filter; and D) electro-optical lens.

Procedures

In bright environments, the visual system is capable of its best resolving capacity (or acuity) and is most sensitive to optical defects; preselected tasks that reflected this were based on Logarithmic-scaled Minimum Angle of Resolution (LogMAR) acuity data, in addition to Soldier marksmanship scoring. The effect of the different lens filters on subjects' ability to adapt to a dim environment, following exposure to a bright environment, was measured by clinical dark adaptation timing measures. Further, the time required to detect and recognize certain objects (e.g., AiR-15 rifle, simulated torsos with various wear) was also logged for statistical analysis.

These human performance measurements were grouped as follows: (1) clinical measurements under bright lighting conditions; (2) operational performance measurements under bright lighting conditions; (3) clinical measurements of adapting from light to dark (dark adaptation); (4) operational performance measurements transitioning from light to dark conditions; and (5) subjective preference of optical device. Visual acuity, marksmanship, and dark adaptation were tested one immediately after the other, and breaks were encouraged between tests. In addition, subjects would take breaks between wearing the lenses when needed, and resting times varied among the subjects. Subjects were trained on the tasks before data collection for familiarization and usage of the rifle setup, and the order of the lens wear was randomized for each subject. Further breakdown of the procedures follow:

Clinical measurements

These measurements assessed best-corrected visual acuity using standard clinical optometric procedures in an eye lane with 50.7 Foot-Lamberts (FL) luminance levels, and using an Early Treatment Diabetic Retinopathy Study (EDTRS) logMAR Visual Acuity Chart (figure 2). The LogMAR acuity scores, as well as the total number of letters read correctly, were recorded with all four filter/sunglass types plus the CC.

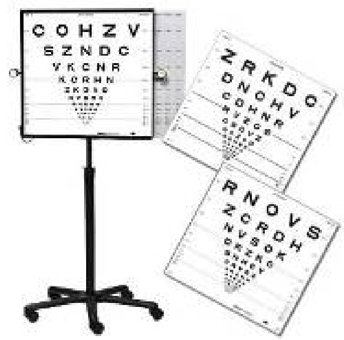

Figure 2. EDTRS Visual Acuity Chart.

Operational performance measurement

The specific criterion for operational performance was precision marksmanship, measured with Olympic competition-quality air rifles as shown in figure 3. Safety procedures for air rifles established by Army Junior Reserve Officer Training Corps for their high school marksmanship program were followed at all times. These air-rifles have been calibrated to levels of repeat reliability and precision that exceed the optical limits of the human eye. Thus, the performance limits of the task are the optical resolution capabilities of the human eye rather than the measurement device. The rifles were mounted into a rigid test fixture and the subject adjusted sight alignment via control knobs on the fixture, thus ensuring the results are due to visual factors (figure 4). An example of the accuracy obtained with an air rifle mounted on U.S. Army Aeromedical Research Laboratory's (USAARL's) rifle mount table is shown in figure 5. The measurements were made with room lighting conditions of 50.7 FL's.

Figure 3. AiR-15 (using an Anschutz 8001 action) and Anschutz 8002 air rifles with computer scoring system. The scoring system reports each shot's score (to a 1/10 point), as well as (x, y) position (to 1/100 of a millimeter). The sights used in the study simulate M-16 (A2) iron sights, which uses the smaller long distance rear aperture of the A2 sight system.

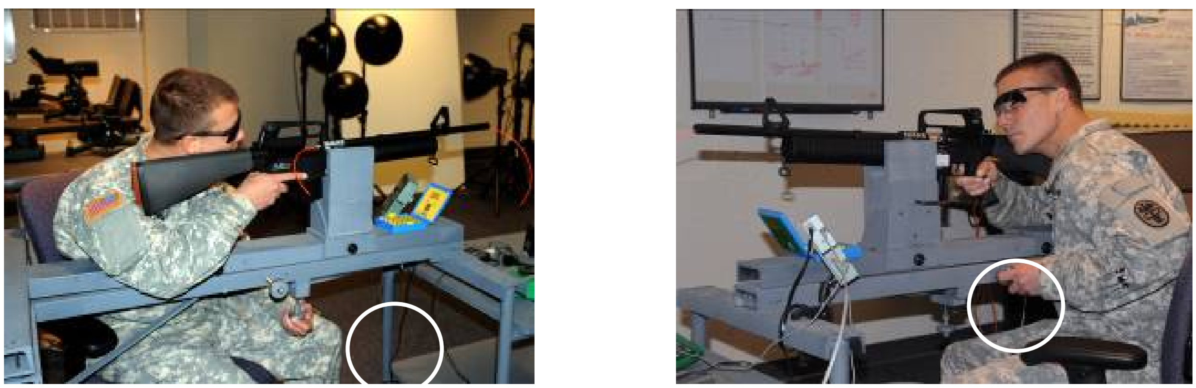

Figure 4. USAARL's purpose built gimbaled rifle mount table. The iron table's gimbaled vise rigidly secures the rifle while allowing for its aim to be adjusted both laterally and vertically. The shooter's task is to aim the rifle via set screws for vertical (elevation, left photo) and lateral (windage, right photo) adjustment and then fire the rifle. A noticeable difference in sight alignment is produced by rotating either of the set screw adjustment knobs one third of a revolution. To reduce mechanical cues, the ambidextrous set screw controls knobs are round and their action has intentional hysteresis. Cord passing through barrel on left photo is a Clear Bore Indicator (CBI) used to indicate the rifle is unloaded.

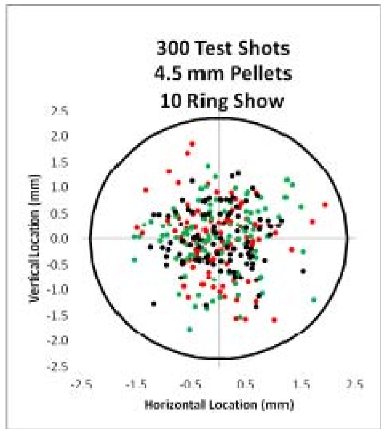

Figure 5. Example of accuracy obtained with an air rifle mounted on USAARL's rifle mount table. The radial error of the 300 consecutive test shots has a standard deviation of 0.40 mm which at the 10 meter range corresponds to 8.35 seconds of arc. For comparison, 1 inch at 100 yards is approximately 57.3 seconds of arc.

Clinical measurements of adapting from light to dark (dark adaptation)

Adapting from light to dark began by exposing subjects to a bright pre-adapting field for 4 minutes in order to reduce their photoreceptor sensitivity. In the present study, the brightness of the pre-adapting field simulated normal daylight conditions. Then the bright pre-adapting field was turned off, with the room illumination reduced so that the subjects were immediately transitioned into a dark environment. The pre-adaptation field was a projection screen illuminated with a light source to produce 1,000 cd/m^2 (figure 6). The task was to report, at different times during the dark adaptation period of 128 seconds, how many of the dark adaptometer lights were visible (figure 7). The 10 lights on the adaptometer varied in brightness by a total of 3.3 log units, decreasing in brightness by 1/3 of a log unit from one light to the next. The brightest was immediately visible at the start of the test period and the dimmest (set at the light level that marks the transition from cone to rod vision, or about 4.5 log trolands) was set to just be visible at the end of the darkened period. The control box allowed any combination of the lights to be on at any given time. As subjects dark adapted, they could sequentially detect dimmer and dimmer lights. The dark adaptometer used in this study was a purpose-built instrument, with a design modeled on classic procedures of measuring dark adaptation so results obtained with it were comparable to results using standard clinical instrumentation

Figure 6. Pre-adapting light field approximates daylight at 1,000 cd/m^2. Subjects pre-adapt wearing the optical device being tested (or no device for control condition) on that run.

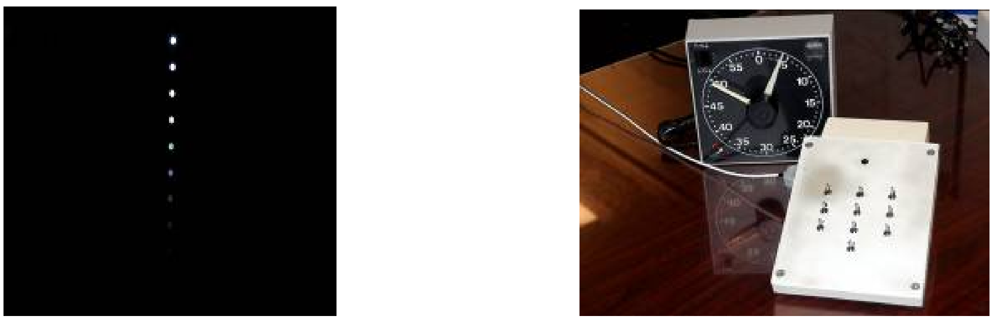

Figure 7. Purpose-built Dark Adaptometer, Control Panel, and Timer. The 10 lights on the adaptometer vary in brightness by 3.3 log units decreasing in brightness by 1/3 of a log unit from one light to the next. The control box allows any combination of the lights to be on at any given time. As subjects undergoes progressive dark adaptation, they can correctly identify the number of dimmer and dimmer lights.

<u>Operational performance measurements transitioning from light to dark conditions</u>

This task was done in conjunction with the light identification task, described in the previous section. The task of the subjects was to identify, as soon as possible, six objects that had been placed on the floor in the dark room. The six objects to be identified were as follows: heads of the torsos, torsos with four different clothing patterns, and an AiR-15 rifle. These objects possessed defined visual characteristics of size, shape, and contrast and examples are shown in figure 8. The subject's task was to detect object presence, then verbalize the localization of as many objects as soon as possible. Secondly, subjects were to verbalize when object recognition, then identification was determined. Thus, scored responses (times of correct detection, recognition, and identification of each of the objects) were all measured per trial. The dependent variable was the length of time required for the subject to correctly locate and identify each of the six objects distributed around the dark room. Each of the subjects was tested individually.

Furthermore, for the duration of this part of the experiment, the subjects remained seated in order to minimize the possibility of tripping or stumbling in the dark.

Figure 8. Examples of targets for the dark adapting task. The torso target dimensions were based on the Army's range "Target F Polyurethane 690000714589" used in rifle marksmanship training. Rifle target was an AiR-15 air rifle modeled after the M16A2 rifle, and rested across the white torso (far left) during the task.

Subjective preference

Finally, the subjects were asked what their subjective preference was for the frames they tested under all the conditions presented.

Statistical analysis

This was a within subject, repeated-measures experimental design with five different independent variables (tests performed) tested under five frame conditions (CC, CL, SL, SF, EO). All collected data were continuous, parametric in nature except for the subjective preference data. For the parametric data, a multivariate ANOVA was used in determining the systematic presence of any statistically significant performance differences within the complex variable matrix (Field, 2009). Post hoc testing was performed to independently assess the effects of the five independent variables (i.e., the five viewing conditions/lenses/filters) on each of the four research segment results. For the nonparametric data, a Friedman test was performed. All significance levels were $p < 0.05$, and statistical analyses were performed with the Statistical Package for Social Sciences (SPSS) 20.0 software.

Results

There were five segments to the study, which evaluated the effect of four different protective spectacle lens designs (CL, SL, SF, and EO) on the subjects' ability to rapidly transition from bright to dim environments. The results are as follows:

Visual acuity assessment

Visual acuity was not significantly affected by any of the lens designs (figure 9). Overall, the EO performed the best with the SL performing the worst. Interestingly, in this brightly lit testing environment, the EO and SF conditions resulted in very slightly improved visual acuity, but not enough to reach statistical significance.

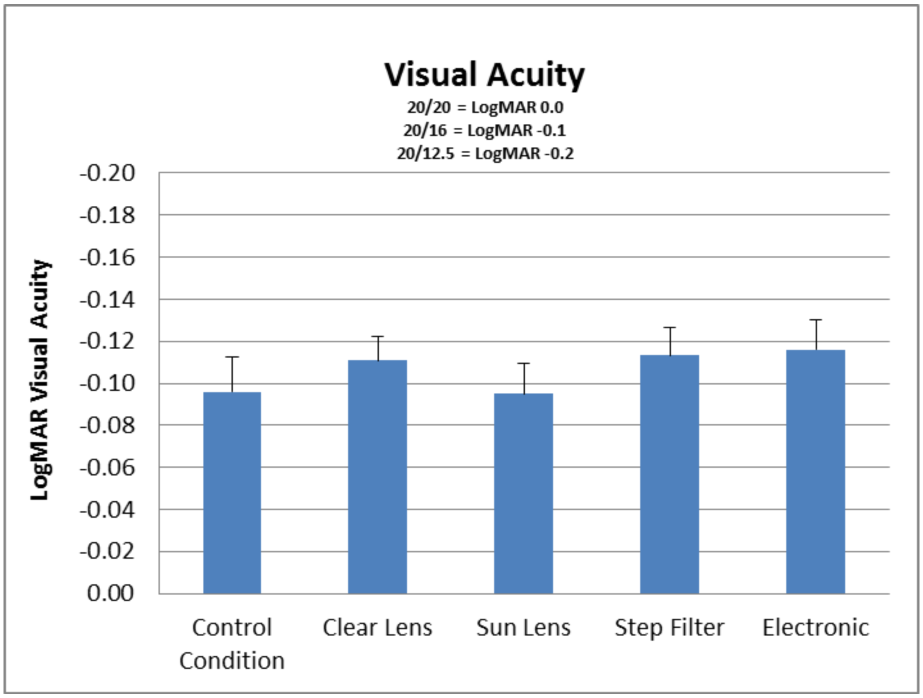

Figure 9. LogMAR visual acuity with each eyewear worn. The error bars display the standard error of the mean (SEM). A higher bar indicates better visual resolution.

Marksmanship performance assessment under full illumination conditions

The average marksmanship scores for the 24 subjects (scored by means of documenting error radius in minutes of arc) under each of the experimental conditions varied considerably (figure 10). Interestingly, the SF marksmanship scoring was somewhat worse than all other conditions, suggestive of difficulty in controlling the viewing condition. The SL and the EO lenses displayed slightly better scoring (on figure 10, a shorter bar represents a tighter error radius, or better marksmanship performance); however, there were no statistically significant differences among all 5 testing conditions.

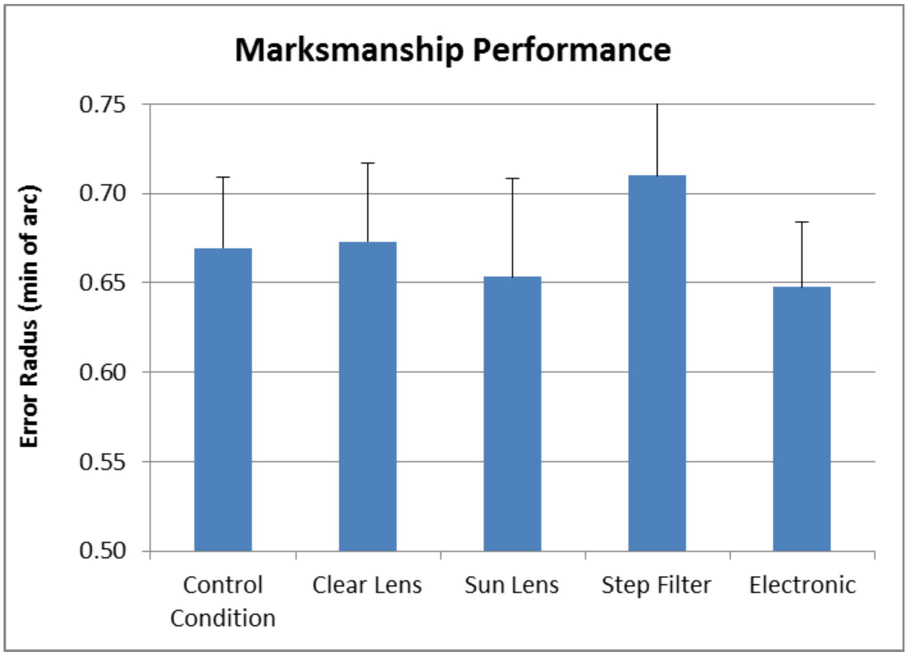

Figure 10. The combined marksmanship data document results for each lens/filter condition. The error bars display the SEM.

Adaptometer determination of dark adaptation profiles (viewed through each of the five different observational lens/filter types)

Dark adaptation responsiveness was most effective while using the SF design, followed by the EO lens condition; the slowest dark adaptation process occurred while using the SL design (figure 11). There was no significant differences in the dark adaptation process between the SF and EO designs; however, there were significant differences between the SF and CC ($p = 0.02$), CL ($p < 0.01$), and SL ($p < 0.001$) lenses.

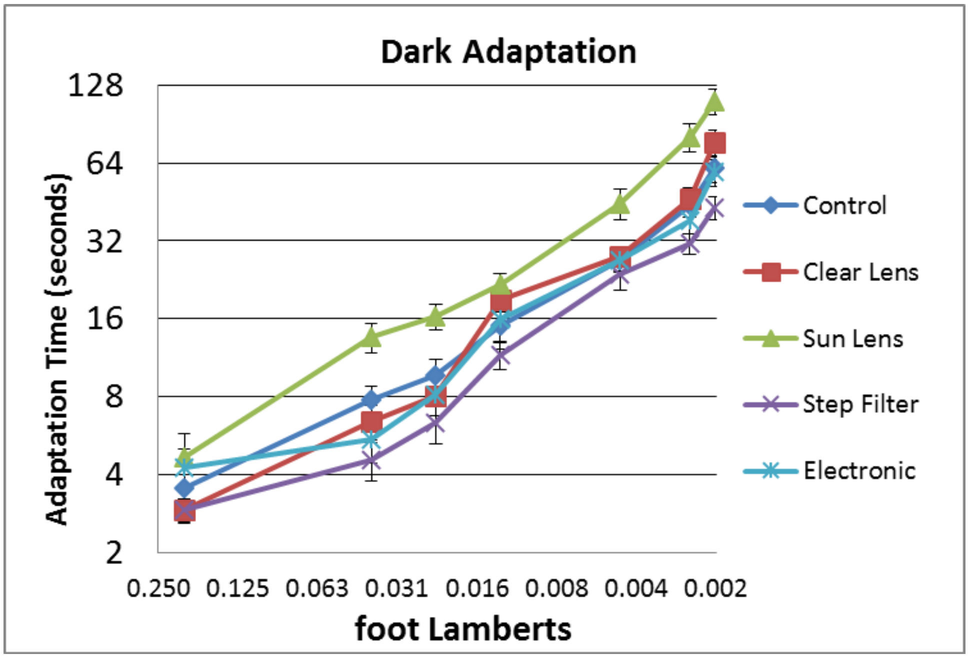

Figure 11. Continuous variable plot of dark adaptation based on length of time required to detect a certain numeric light configuration. The error bars display the SEM.

Object detection/resolution processes ensued throughout the dark adaptation period

Subjects consistently noted the ACU-wearing cutout required the greatest length of time to detect and to identify under all of the various lens/filter conditions (figure 12). In addition, when objects were grouped together, the SF design condition performed the best followed closely by the EO lens design (figure 13). There was no significant difference in performance between the SF and EO lens; however, there were significant differences in performance between the SF and CC ($p = 0.04$), CL ($p < 0.001$), and SL ($p < 0.001$). In addition, there were significant differences between the EO lens and CL ($p < 0.016$) and SL ($p < 0.003$) lenses.

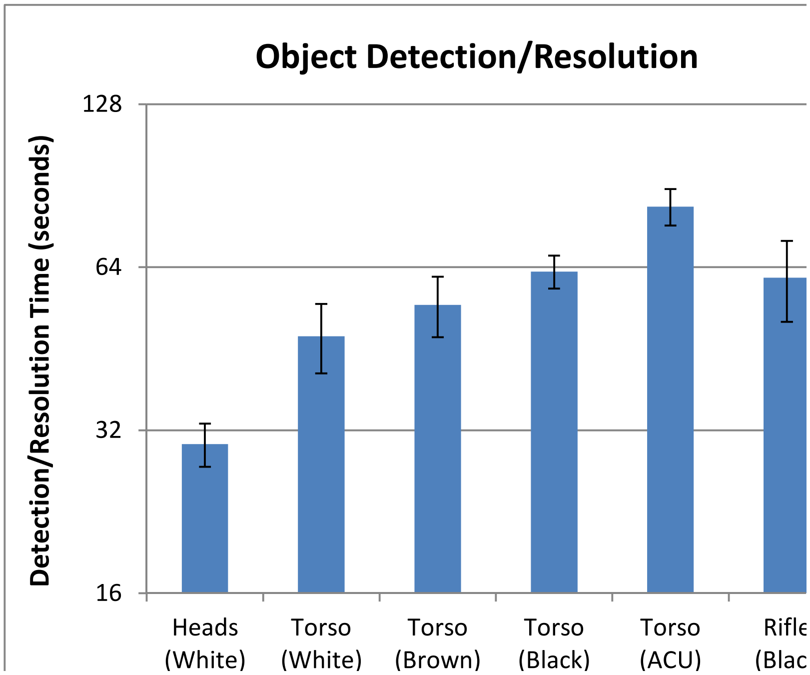

Figure 12. Dark adaptation object detection task of the grouped lens/filter data. Error bars represent the SEM.

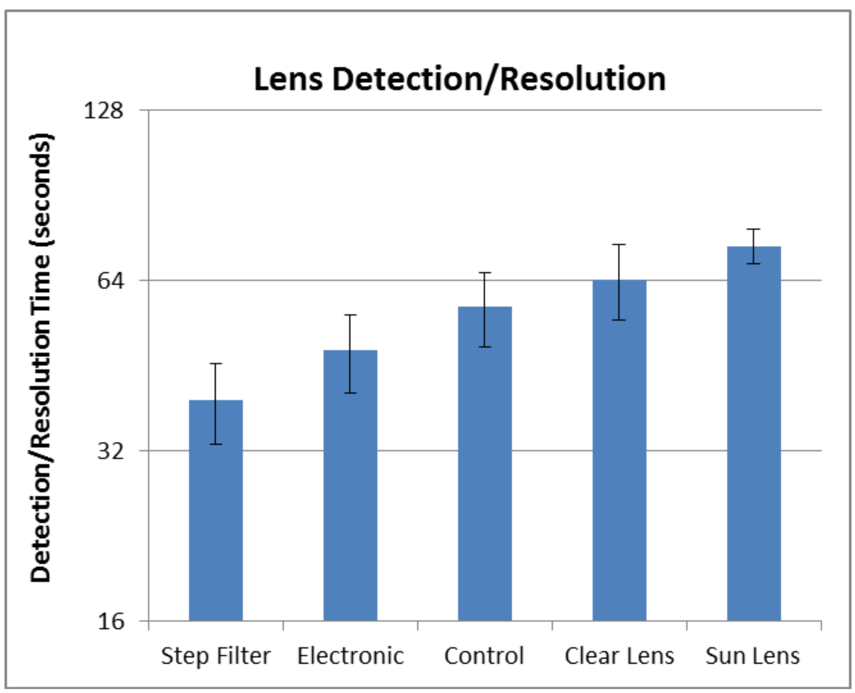

Figure 13. Lens Detection/Resolution times collapsed over targets. Pairwise comparisons indicate the SL was better than the CC, CL, and SL. Error bars are the SEM.

Subjective preference

Subjects were asked to rate the ease of their light to dark transition for each of the experimental conditions (scoring 1 for best, and 2 to 5 for sequentially poorer performance). The preference ratings revealed the SF and the EO eyewear were preferred over the CC, CL, and SL (figure 14). Essentially no significant difference in preference was found between the SF and the EO conditions. However, the SF did hold a 0.5 point preferential scoring advantage over the EO system.

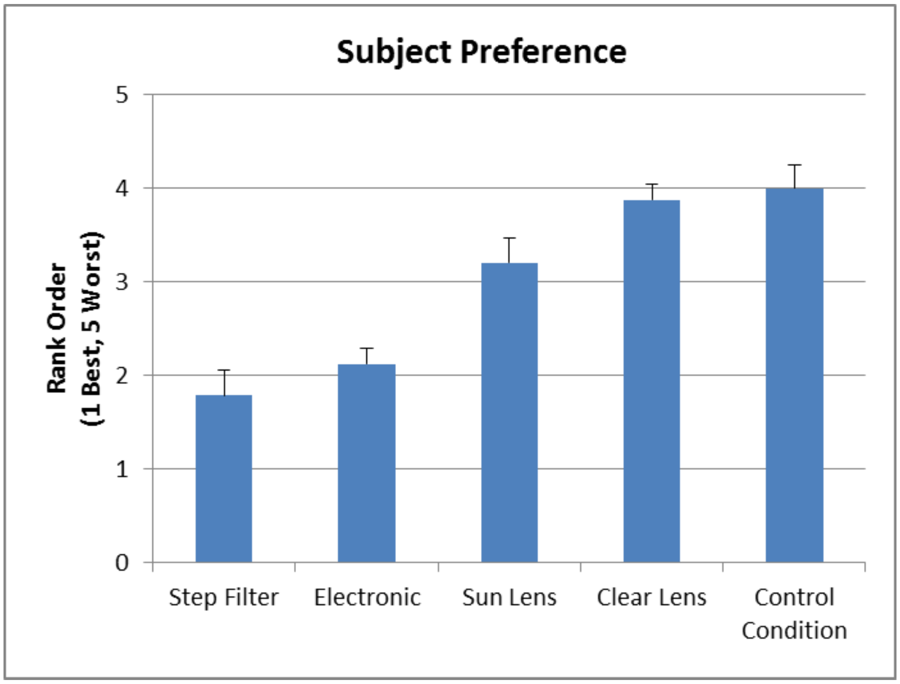

Figure 14. Subject preference results of eyewear. Error bars are the SEM.

Discussion

The study was commissioned by the U.S. Army Program Executive Office for Soldier Systems (PEO-Soldier) to determine the optimal method (within the reach of current technological limitations) to permit Soldiers to transition from one level of illuminance to another, with a minimum of distracting glare or blur. Visual acuity and marksmanship, which are important indicators of performance in combat, did not vary significantly across the five eyewear conditions. Dark adaptation curves indicated the most effective lenses worn were SF, whereas the slowest dark adaption occurred wearing the SL design. The dark adaptation profiles obtained on the adaptometer's test-light identification task closely matched those profiles established in the dark adaptation test-object-identification task (figures 11 and 12) with the heads (white) being the quickest to identify for group of optical devices and the torso (ACU) being the slowest. A recent study (Patryas et al., 2014) demonstrated a direct dark adaptation performance difference related to macular pigmentation density, which could have been manifested as a performance difference within our data. Subject-specific analyses could provide insight toward defining specific visual performance variation sources that occurred across our subject pool.

Finally, subjectively the SF option was preferred over the EO lens, but not by a statistically significant margin. The time needed to reach up with one hand and turn the electro-optical system on or off was both a performance decrement and a distraction with respect to individual responsiveness; thus, the potential operational cost of such delays could comprise mission performance.

Conclusion

Both “transition” type optical lenses assessed in the present study (SF, EO) performed well. Overall, the SF lenses were slightly more preferred over the EO lenses, and the added risk of the warfighter having to reach up with one hand and turn the EO lenses on or off may add further reason to use the SF lenses. If the technology fielding decision is governed by the standard acquisition matrix of cost, schedule, and performance, then the less expensive option, with fewer secondary field issues (e.g., no battery requirement, no added weight, etc.) will likely be preferable. But future technological developments could alter the decision factors in another direction, reinforcing the need to continuously monitor the technologies that are developed.

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